Ethanol driven building fungus colonisation: 'Whisky Black' in urban built environments

Introduction

The Distilling Industry

The whisky[1] industry is key to the Scottish economy, contributing £4.37 billion pounds in 2017, providing around thirty-five thousand jobs (O'Connor, 2018), and being of higher export value in 2018 than oil and gas (Scottish Government, 2020). Notably, it is predicted to grow significantly, with many distilleries greatly increasing their stocks for future output (Cave, 2016). The industry's espoused image is one of adhering to traditional historically preserved processes and practices followed in distilleries in picturesque rural surroundings. This image is reflected and promoted in tourism marketing such as Visit Scotland, noting of the thickly distillery populated Speyside valley, that "this breath-taking area sits in a fertile valley of rivers and secluded glens and is home to over half of Scotland's distilleries" (Visit Scotland 2020). However, whilst operations conforming to these descriptions do undoubtedly contribute to production, much whisky is manufactured in denser urban environments and on a significantly larger scale than these 'bespoke' craft-oriented operations.

All 133 locations where whisky is produced in Scotland are licensed by the Scotch Whisky association. Whisky manufacturing stages include; malting, fermentation, distillation, and maturing. Importantly the spirit must mature for a minimum of three years within a warehouse in Scotland before it can be classified as 'Scotch Whisky' (O'Connor, 2018), although commonly, maturation (or aging) is much longer. The whisky is matured in oak barrels in bonded warehouses, and some of the spirit evaporates through the apertures of the wooden barrels (Mosquin, 2011). It is estimated that 2% of its volume evaporates into the air annually as ethanol (Byland, 2012), affectionately known as the 'Angels share' (Dixon, 2009). Approximately twenty-two million casks of whisky can be found in maturing warehouses throughout Scotland (Scotch Whisky Association, 2020). From these, a significant amount of ethanol is released into the air each year throughout the country, and it is this ethanol that is key as it feeds the Whisky Black fungus found on buildings and substrates on numerous sites across Scotland in close proximity to bonded warehouses.

Baudoinia Compniacensis **(Whisky Black)**

Baudoinia compniacensis (hereafter *B. compniacensis*) is a fungus known for staining exterior surfaces of, for example, buildings, trees, and street furniture in the presence of ethanol vapour (Ewaze *et al*, 2007). As such, it is found in the vicinity of bakeries and bonded warehouses, and is commonly referred to as 'warehouse staining'.

The fungus colonises these substrates and digests the ethanol vapour produced by, for example, whisky ageing in oak barrels in bonded warehouses. *B. compniacensis* is capable of metabolising carbon sources including ethanol, glucose and acetate, and thrives in exterior settings with low levels of ethanol vapour (5 to 10 ppm) in the atmosphere (Ewaze *et al*, 2008). In the presence of ethanol, the fungus expresses the enzyme alcohol dehydrogenase II (ADH II). This leads to the metabolic pathway whereby ethanol is converted via intermediate molecules to a form that enters the TCA cycle (see final stage in Figure 1). Interestingly, higher levels of ethanol appear to prevent growth and colonisation, though the specific reasons for this are as yet unknown.

[1] Spelt 'whiskey' in many parts of the world

C_2H_5OH (Ethanol)

↓

C_2H_4O (Acetaldehyde)

↓

$C_2H_3O_2$ (Acetate)

↓

Tricarboxylic Acid (TCA) cycle

Figure 1: Simplified metabolic pathway for ethanol taken up by *B. compniacensis.*

The fungus is known to exist worldwide, and has been reported near distillery warehouses and bakeries in many countries that display varying environmental conditions. One key feature of *B. compniacensis* is its ability to withstand extreme temperatures, with dried cells found to survive in temperatures as high as 70°C (Ewaze *et al*, 2007). Scott *et al,* (2007) investigated the prevalence of this fungus and found five geographically constrained strains of *B. compniacensis.* These are *Baudoinia antilliensis* (the Caribbean), *B. caledoniensis* (Scotland), *B. compniacensis* (France), *B. orientalis* (Korea), and *B. panamericana* (North America). As well as acting as a nutrient, ethanol is a germination activator and inducer of cellular stress responses for *B. compniacensis*, which may explain the prevalence of this fungus near bonded warehouses that store whisky (Scott and Summerbell, 2016).

The fungus germinates to produce filamentous germ tubes. In laboratory conditions *B. compniacensis* is slow growing, with broad black radiating subsurface hyphae (Scott *et al*, 2007). On outdoor surfaces near bakeries and bonded warehouses *B. compniacensis* forms a thick soot-like crust (Scott and Summerbell, 2016). These surfaces include masonry, stainless steel, and paint and vegetation, but appear to exclude copper or zinc-clad surfaces.

Scott and Summerbell (2016) proposed a 4-stage growth cycle over the course of a day for *B. compniacensis* (summarised in Figure 2).

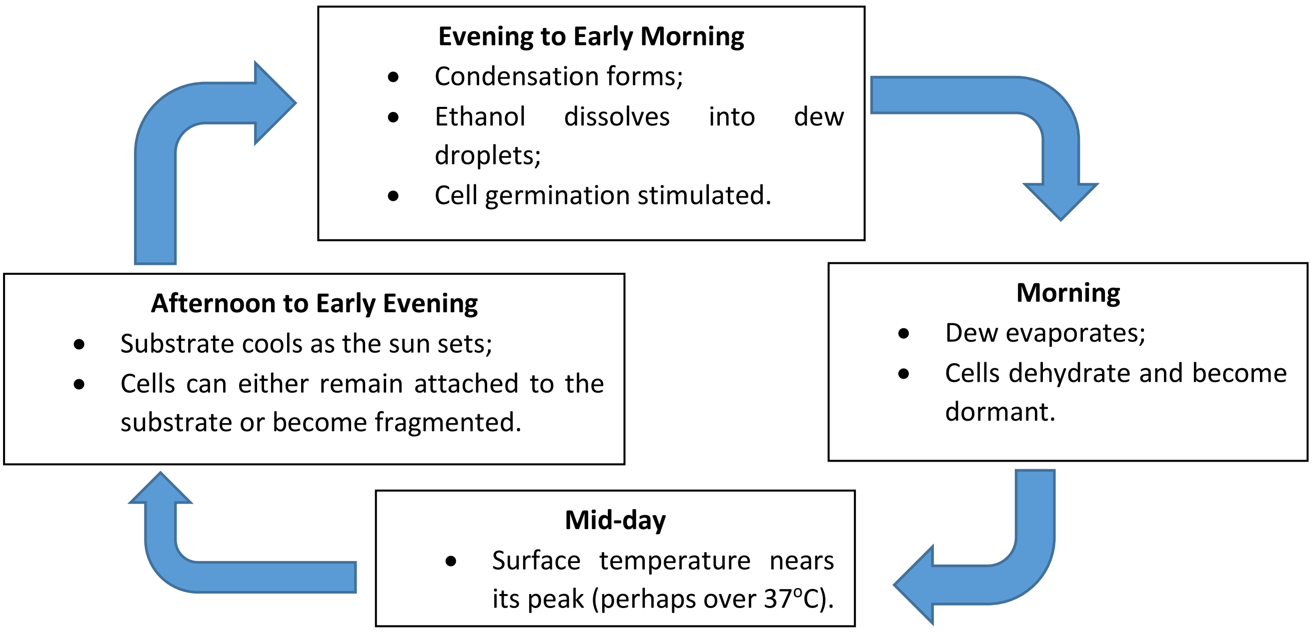

Figure 2: Generalised daily cycle of *B. compniacensis*, proposed by Scott and Summerbell (2016).

The impact of *B. compniacensis* on buildings

The phenomenon of darkening of buildings, vegetation and street furniture in the vicinity of spirit maturation warehouses as a result of fungal growth was established over a century ago (Richon and Petit, 1881). Subsequent studies show that blackening of buildings near industrial spaces producing ethanol is almost exclusively a result of fungal growth feeding off the ethanol (Ewaze *et* al, 2007; Scott *et al*, 2016; Scott and Summerbell, 2016; Watson *et al*, 1984)

Fungi preferentially grow on substrates with higher moisture content that are often exposed to high levels of wind-driven rain or high levels of dampness. Consequently, objects and structures in the vicinity of where whisky is matured, may offer receptive sites for growth, depending on the materials used in the construction of their external envelopes (Scott *et al.*, 2007; Mosquin, 2011). Indeed, homeowners residing near whisky bonds have voiced concerns over a thick black mould commonly referred to as 'Whisky Black' covering their houses, cars, garden furniture, nearby trees and lampposts (Bell, 2012), and the negative implications of this on their property's value.

The temperate climate in Western Scotland of cool summers, mild winters and frequent rainfall in accordance with the seasonal average (Environment Scottish Government, 2014) presents ideal climatic conditions to encourage the growth of *B. Compniacensis.* Given the high frequency of wet weather, ethanol will preferentially dissolve into liquid water from the atmosphere.

Compounding this, external walls and wider external building envelopes are ostensibly constructed using porous building materials that absorb and retain moisture from the environment (McCabe *et al.,* 2013), and depending upon their pore structures they remain damp, thereby creating favourable environments for the propagation of *B. compniacensis.* Any soiling on an external building envelope is unlikely to be uniform as deposition and growth patterns will depend upon the nature of surface material (such as natural stone, that can exhibit variability in pore distribution and permeability across the material) and any particular features of a building, such as eaves and soffits, which will provide shelter to certain parts of the structure and influence surface rain water 'run off' patterns on a building (Andrew, 1994). Thus, precisely how the production of spirits and any resultant fungal growth occurs in the surrounding environment is highly complex and influenced by a range of different materials and conditions.

Legal disputes relating to blackening of buildings

Brewing and distilling companies have consistently denied any culpability for the blackening of buildings near their warehouses, instead insisting that such fungal growths on nearby buildings occur naturally (Ryzik, 2012; Borland, 2012) and not from spirit production methods.

Nevertheless, there have been legal cases whereby owners of nearby buildings have sought redress for the cost of cleaning their buildings, and loss of potential property value. One US case (Merrick et al v Diageo Americas Supply Inc., 2015, cited in Bishop, 2016) found in favour of the plaintiff, resulting in the defendant agreeing to stop housing barrels in certain warehouses; however, the defendant continues to insist the mould is naturally occurring.

In Scotland, one case taken forward (Chalmers v Diageo Scotland Ltd, 2017, cited in Craig, 2020) is both nuanced and long-running. Initially filed in 2005, in 2006 the agency Health Protection Scotland (HPS) was tasked with discovering the cause of the fungus. HPS found that the cause of the blackening was not related to fungi caused by the ethanol vapours (McRae and House, 2006).

However, criticisms were made of the HPS investigation, and the pursuers (plaintiffs) have appealed against the initial decision. Their appeal notes that the HPS team used a medium and incubation temperature unsuited to many common environmental moulds such as *B. compniacensis*, and failed to carry out a microscopic comparison of the culture results and structures present in the scrapings. Further, the HPS investigation relied on one publication by Watson et al., (1984), and failed to consider more recent scientific papers. Further scientific investigation was allowed by the courts, and the case continues.

'Whisky Black' and the distilling industry

The claim against whisky distillers is controversial because of the industry's economic size, importance to the tourist industry, and its integral value for communities throughout Scotland (Ryzik, 2012). If property owners were successful in obtaining compensation from producers, the total value that would need to be paid out across Scotland alone has been estimated at five-hundred million pounds (Allen, 2012), which would have a considerable impact on the producers and distillers. Moreover, some argue that warehouse staining adds to the architectural character of distilleries and bonded warehouses and can in fact be attractive (Curtis, 2004); a perspective resonating with Ruskin's ideas of 'patina' that add to historic building character (Ruskin, 1849; 1851). Indeed, Marshall (2019) comments that many live with the fungus and 'talk fondly' of whisky and the jobs it supports. Whilst this is hard to reconcile with fungal growth on new-build properties, there is arguably a case for a negotiated settlement between the distillers and those living nearby that could take account of the impact the fungus may have on the value of a new-build property, but at the same time recognise the value to the economy that the industry brings.

Despite the industry's claims the fungus occurs naturally, it is indisputable that ethanol is released into the atmosphere through whisky maturation, and it has been shown globally to act as carbon nutrition for the black mould growth *B. compniacensis* in favourable growing and culturing conditions (Ewaze *et al.,* 2007; Al-Naama *et al*., 2009).

Cleaning of buildings blackened by *B. compniacensis*

Perhaps reflecting increased production, the growth of Whisky Black in the areas around whisky bonds has been noted to have worsened over time (Borland, 2011). Exterior walls and roofs in surrounding areas are believed to be stained by *B. compniacensis,* along with a range of other items such as trees, gutters, fencing (Morris, 2013), cars, and telephone boxes (Milmo, 2014; Ramage, 2017). Macias (2016) comments about a walking tour of a scenic facility in a US whiskey producing area in Tennessee, and describes the surrounding trees looking like they had had their bark 'blowtorched'; although the distillery manager claims the locals are not concerned. Residents of one Scottish town consider it the root of a diabolical blight on their properties (Milmo, 2014) and Rogers (2011) even notes finding an old stainless steel tank in the vicinity of bonded warehouses with black fungus growing all over it, clearly implying the pervasive nature of the growth, given the rationale for having stainless steel is its very resistance to staining.

Furthermore, communities in Kentucky have noted that black fungus continually returns despite deep cleaning of the outside of their homes (Marshall, 2019), a phenomenon also noted by Ryzik (2012). One resident in Kentucky reported that a building could be cleaned but once again turn black and become discoloured in less than a year (Ryzik, 2012). Importantly, the removal of surface soiling can be complex, and many cleaning processes have unintended negative consequences for the materials forming the substrate (Webster, 1992). Indeed, aggressive chemical cleaning agents have been previously associated with deterioration in natural stones, adversely affecting their binding cementing matrix.

In light of these issues, residents in one Scottish town are appealing for an annual 'clean up levy', but during a recent planning application made by the distillery, they were told that the debating chamber was not the place to consider these issues (Ramage, 2017). The solution to the problem, according to Milmo (2014) and The Scotsman (2017), could be the installation of oxidising and abatement equipment which could capture the ethanol at source (Hodge and Devinny, 1994), such as the capturing equipment used by Brandy distillers in California (Marshall, 2019). Yet, previously, Morris (2013) noted that distillers are already operating within environmental guidance (air permits) and questions why they would want to manage ethanol emission levels.

'Whisky Black' on buildings in West Central Scotland

Drawing on a Building Pathology framework for "the systematic investigation and assessment of building defects" (CIB 1993), here we investigate the growth of Whisky Black in West Central Scotland. We present data aiming to establish any patterns of growth and consider the consequences of the fungus on the buildings of properties located near bonded warehouses. At the outset we must outline that testing for ethanol was not undertaken within the surveyed area, but the prevalence of the 'staining' across the buildings indicates that the fungus is flourishing (because the fungus will not grow without the presence of the ethanol) not only in this location but also in a number of other locations across Scotland as identified by Scott et al., (2016) and Ing et al., (2018).

To complement existing research in the field, in this paper, data is analysed and discussed against existing related studies and the key building pathology protocols of:

- Manifestation of defects (namely a deficiency or shortfall in performance of the original conditions in the materials noted);
- Diagnosis (considering the likely causes of these defects);
- Prognosis (the ramifications of such defects if left unattended) and;
- Therapy (treating the defects and introducing measures to avoid such defects in the future).

This paper surveys the colonisation of the fungus on the urban environment. Areas of prevalence of Whisky Black are identified, with a systematic characterisation of the blackening of building surfaces. This is considered in relation to the distance and direction from the putative source of ethanol (the bonded warehouses). Recommendations are made for further research regarding the ramifications of any growth on breathable substrates or porous building materials. Furthermore, any therapy suggested is done so in relation to materials performance and remedial treatments. This novel approach provides a practical direction for future research and for tackling and resolving the related issues for usage worldwide.

Methodology and approach

Approach to Investigations

The approach to data collection for this paper was one not adopted elsewhere as far as the authors are aware. Primary collection was undertaken by a process of surveying domestic buildings in a geographically constrained area. This constituted a comprehensive visual survey. In many ways this approach is akin to a case study. When case study research is utilised, there is often a characteristic about the subject which is unknown (Gillham, 2000) and although the subject of Whisky Black is known, the actual extent of the problem is not fully understood. A key advantage of case study research is that data can be represented with clear descriptive examples (Fellows and Liu, 2015), thereby allowing for comprehensive insights into the phenomenon of Whisky Black and its effects on the surrounding built environment. Although case studies have often been criticized for an inherent lack of generalizability, as Flyvbjerg notes, the theoretical findings and implications of case studies are generalizable to other contexts (Flyvbjerg, 2006). Indeed, if Whisky Black is found in the area of one bonded warehouse with particular climatic conditions, its pathology can be expected in other similar areas because the presence of maturation and not distillaration will determine whether the fungus thrives (Ing *et al.,* 2018). Following the review of the literature it became apparent that, as far as the authors are aware, there is no information available on the extent of Whisky Black growth across residential properties, and consequently an observational fieldwork technique through a visual survey was undertaken in an attempt to record and quantify the extent of any growth.

Methodology

Given the large scale of this colonisation, the case study method selected focused on one area of West Central Scotland affected by the fungus. This was a residential area in close proximity to the bonded warehouses situated on the edge of the town. The topography of the location is indicated in Figure 6 (see below) which highlights that part of the site is surrounded by small hills with the location itself being between 2m and 8m in elevation. The proximity to the bonded warehouses, the prevalent climatic conditions, and the fact that at greater distances from the warehouses the blackening of surfaces was reduced, lead to the assumption that the blackening is caused by the fungus rather than by another source, as outlined in Watson et al., 1984, Ewaze et al., 2007, Scott et al., 2007 and Scott and Summerbell, 2016. The prevailing wind is particularly important as it determines the movement of air mass. In this case study the prevailing wind is predominantly from the South West (see Figure 5) and so the food source material (the ethanol) is travelling perpendicular to the prevailing wind and driving rain direction, which demonstrates that the Whisky Black fungus requires only minimal food source to survive and manifest. Other sources of blackening could be, for example, coal fires but the area under consideration is within a Smoke Controlled Area under section 18 of the Clean Air Act 1993. A visual survey was carried out on these properties to identify the extent of manifestation of the Whisky Black fungus to their exterior surfaces, something evident across the literature but not yet recorded or systematically observed in this way before. Data collection consisted of survey notes taken at the time in the form of quantitative data. To ensure reliability and consistency (Bryman and Cramer 2009) and to maximise "the extent to which research produces the same results when replicated" (Bloor and Wood, 2006, p.147), observations were undertaken by a team of three (one main investigator and two data recorders). The process of observation involved the three observers working together in a structured manner taking each building in turn and the recording the results of their observations from the overall extent of staining. The team were very close to the data and this enhanced reliability and strengthened inter-rater reliability (Thompson *et al.,* 2004).

Field note tables consisting of tick box forms were constructed prior to the visual inspections, one for each property to be surveyed. Properties surveyed were also plotted on an Ordnance Survey map of the area, and for each property, elevations were considered by orientation: for example, North, East, South, and West. Within each elevation individual construction materials were assessed to include; brick, timber, PVC, re-constituted stone, and roughcast. A Likert scale (1-4) was used to determine the extent of manifestation of Whisky Black on each elevation and each construction material. The scale included the following variables; very heavy (represented by black indicators), heavy-medium (dark grey indicators), light-very light (light grey indicators) and no visible soiling (white indicators). Field note tables also allowed for comments or observations to be written down by the research team during the inspections.

Once all surveys were complete, the survey observations of 50 properties in close proximity to the bonded warehouses were then plotted on an Ordnance Survey map of the area. All research undertaken had been planned in line with the relevant institutional ethics procedures and with a keen focus on ethics. For example, when undertaking the fieldwork, the surveying team did not enter any areas of property i.e. residents' gardens or driveways. The surveys were carried out from the centre of the public road, thereby respecting the privacy of homeowners. Furthermore, although the fieldwork was undertaken from the public road, and in line with standard ethical procedures, Police Scotland were notified in advance of the fieldwork.

Results and analysis of the fieldwork

Data were collected on the overall extent of manifestation of the black fungus on each elevation of the properties assessable from the public road. The fifty properties forming the data subjects of the survey are located to the North-West and West of the bonded warehouses, perpendicular to the prevailing wind direction. These 50 properties are spread over five streets, and include four different construction types. The property types include modern timber frame construction with outer brick and roughcast finishes, others believed to have been built in the 1950's consisting of a roughcast finish, most likely on brick and block cavity wall construction, a bespoke house built from granite, and some again of timber frame construction with brick and roughcast finishes with re-constituted stone quoins.

Construction materials considered were; brick, timber, PVC, re-constituted stone (to include cills, lintels and quoins) and roughcast. Elevations were considered by their orientation, i.e. North, East, South, and West. Where the elevations were placed on the Likert scale adopted, this was determined by the lead researcher regarding the extent of the black fungus on the actual property and exterior material. Care was taken to approach each property with the same level of critique to ensure the data was consistent throughout the visual inspections of all fifty properties.

Each property was found to be affected by manifestation of black fungus on the external envelope of the building. However, the extent of growth varied significantly. One particular property had suffered from fire damage; data could not be collected from this property as it was difficult to distinguish what was fire damage from potential Whisky Black.

Figures 3 and 5 illustrate the extent of black fungus manifestation across the elevations of the fifty properties, by overall percentage of affected elevations in Figure 3 and by the presence of the colour coded system (in the form of a circle/dot) in Figure 5. The majority of the manifestation on the elevations was heavy-medium and of the four per cent of the elevations that were reported to be clean, (totalling five elevations) four of these elevations belonged to the one property at Location Four that had been recently cleaned. Thus, of the fifty properties visually inspected, only one property was completely clean of any manifestation of the fungus.

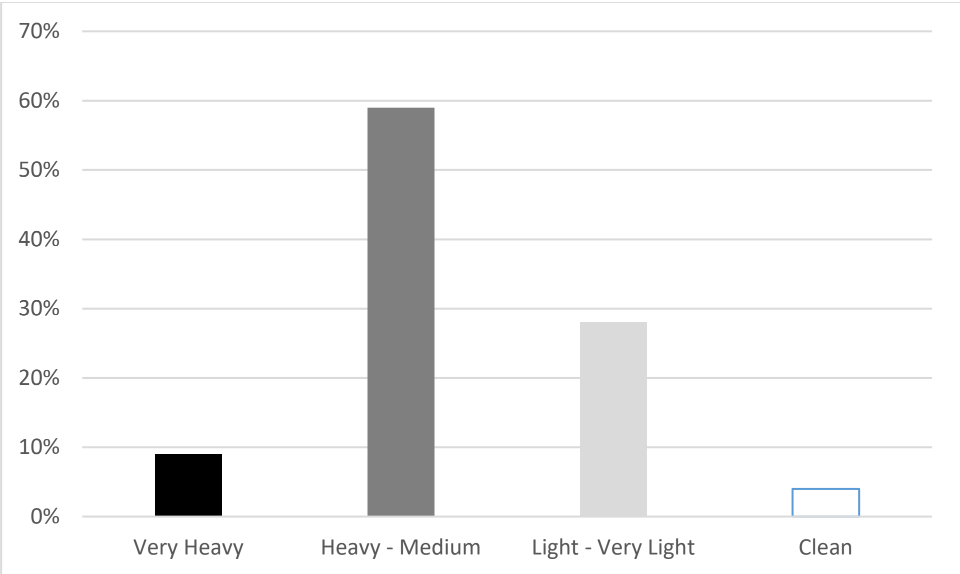

Figure 3: Extent of manifestation on all elevations.

During the visual survey of the properties it also became apparent that in some locations the manifestation of Whisky Black appeared more severe than in other locations. The location of the fifty properties and the spread and severity of the manifestation of the Whisky fungus is presented in

Figure 4. Properties located in Locations one, two and three (twenty-five properties) are considered to be to the North West of the bonded warehouses, properties at Locations four and five (twenty-five properties) are to the West of the bonded warehouses.

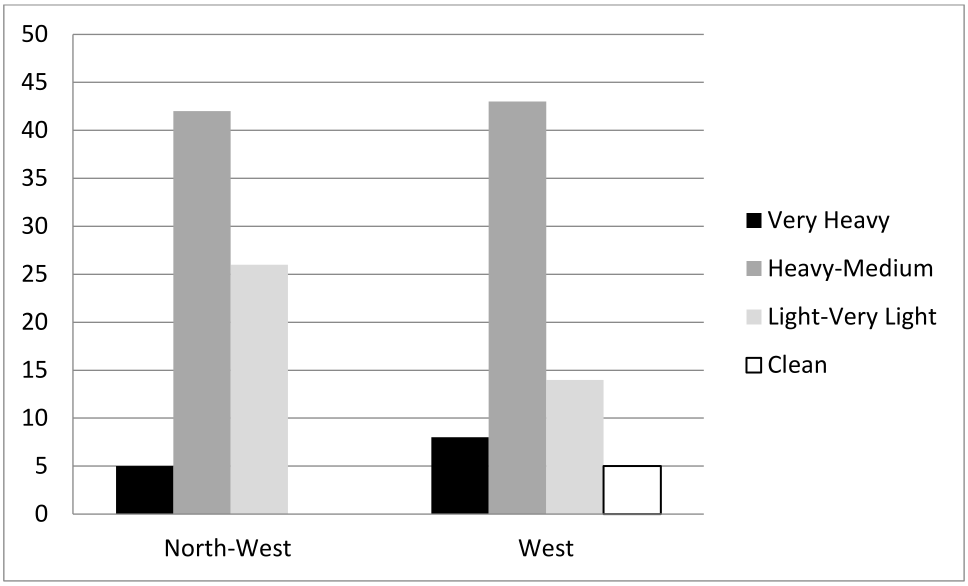

Figure 4: Extent of manifestation by location (number of elevations). The directions listed are relative to the bonded warehouses.

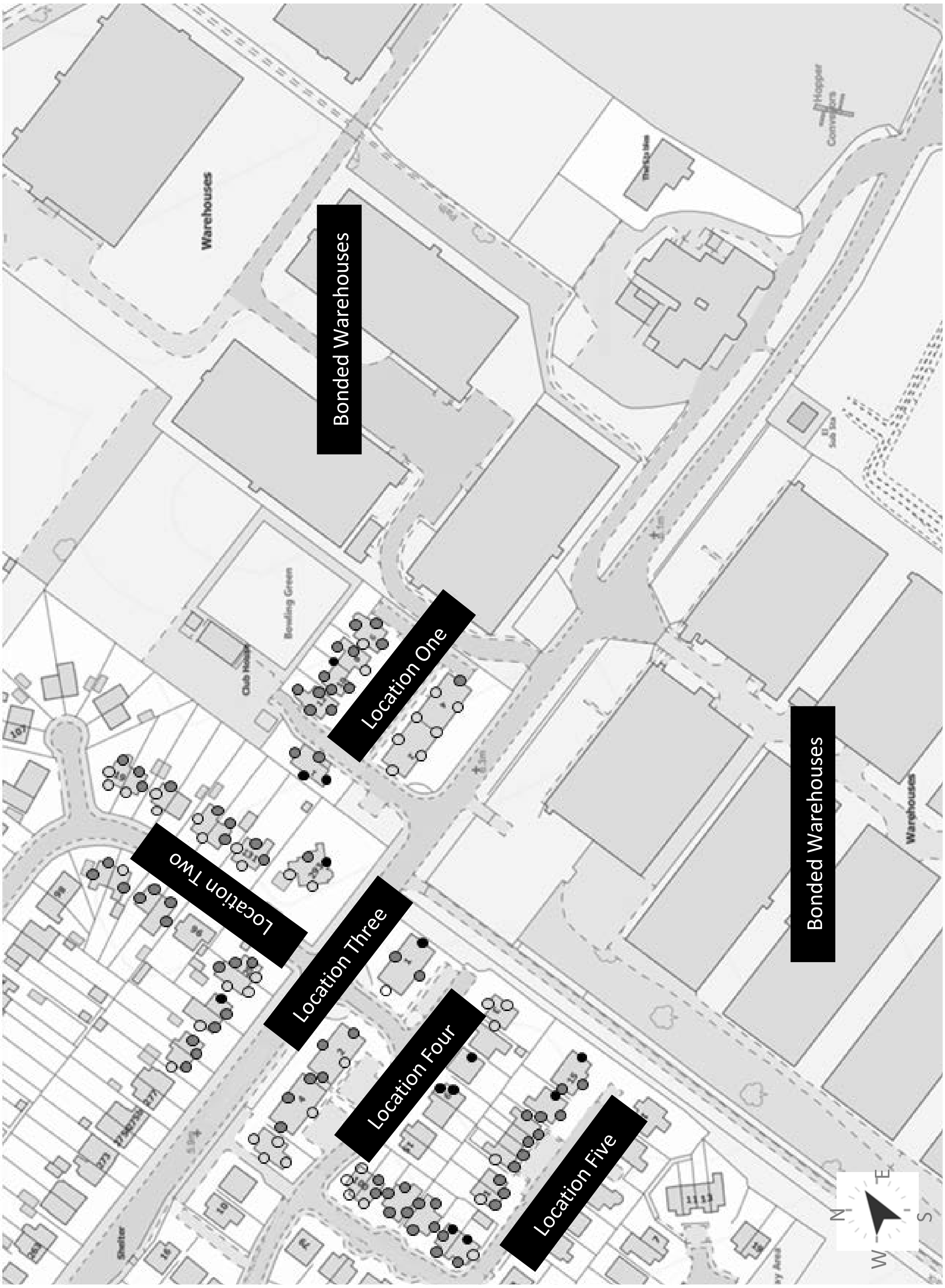

Figure 5: Whisky Black growth on all elevations.
Figure 5 shows the relative positions of locations one to five in relation to the bonded warehouse. The circles highlight the locations of properties surveyed; white circles denote clear; light grey denote light-very light manifestation; dark grey denotes heavy-medium manifestation; black denotes very heavy manifestation. Whilst the number of elevations which have a heavy-medium

growth of Whisky Black is similar in each location in Figure Four, the West has a greater number of elevations which have very heavy manifestation, and fewer elevations with a light-very light growth. However, the severity of manifestation varied significantly within the North-West group of properties and appeared prominent in some areas.

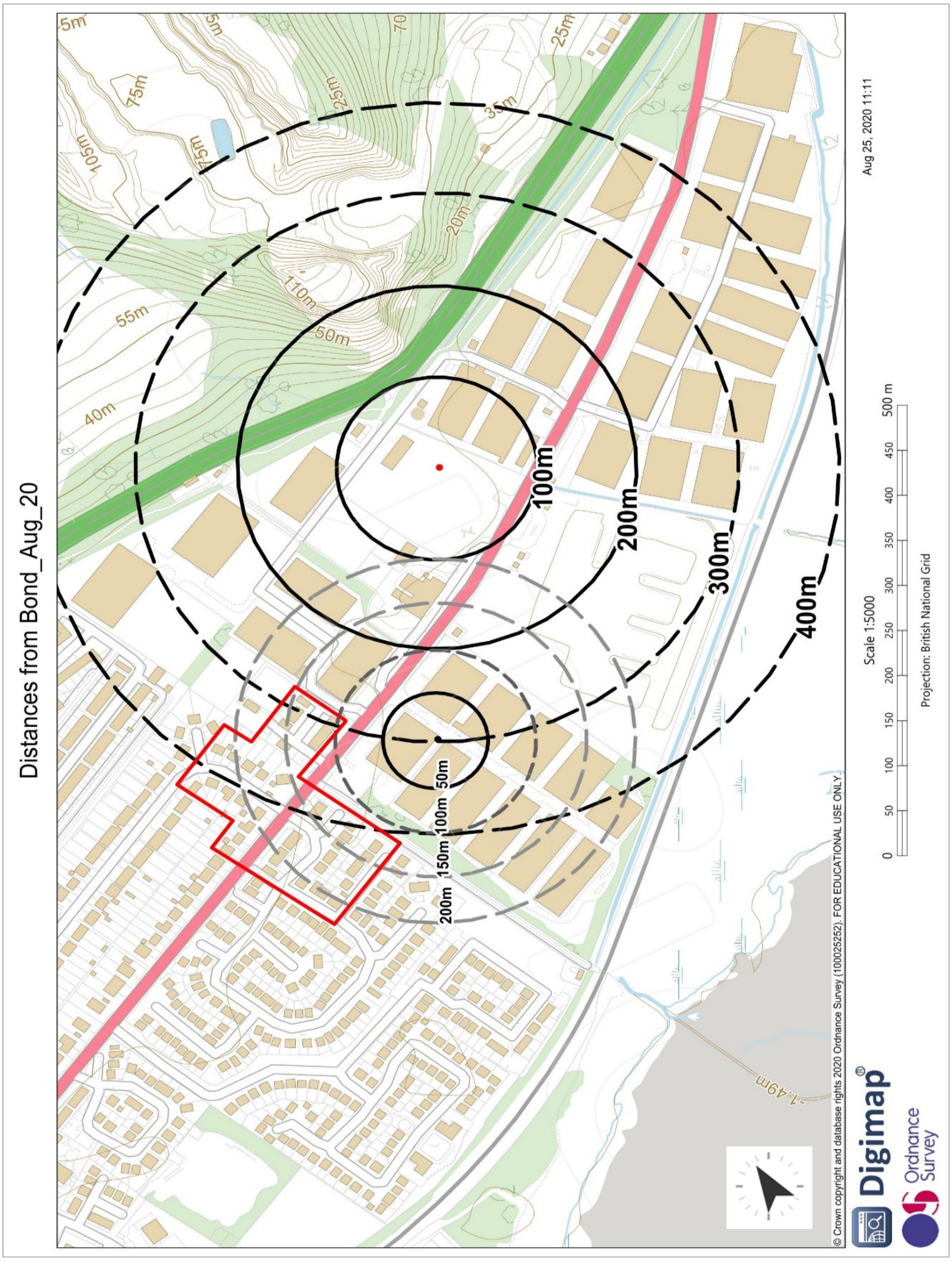

Figure 6: distances (in 100m radius) from the centre of the bonded facility. The second (smaller set) of distance radiuses (50m) are from the centre of the bonded warehouses which are closer to the properties surveyed for Whisky fungus. Location of the properties surveyed is shown by the red line.

Figure 6 indicates the relative distances from the bonded warehouse to the properties surveyed. Of interest is the effect that distance has on manifestation of the fungus. We can presume that the food source (the ethanol) required for the fungal growth is prevalent across the whole of the bonded warehouse facility and it's not just the bonded warehouses in closer proximity that are contributing to the overall growth of the fungus. What is also noticeable is that the location of the properties surveyed (as displayed within the red line) are perpendicular to the prevailing wind direction in this location (from the South West).

The information displayed in Table 1 demonstrates the extent of the Whisky fungus in locations one to five. These figures highlight that location two was the least affected by the Whisky fungus as there are no properties suffering from very heavy manifestation and a higher percentage of homes suffering from light-very light manifestation. Properties in location two are the furthest from the bonded warehouses (as shown in Figure 5).

Table 1: Extent of manifestation on properties at each location

		Very Heavy	Heavy / medium	Light / very light	Clean
Extent of Growth by Location	**Location one**	11%	62%	27%	0%
	Location two	11%	50%	39%	0%
	Location three	0%	59%	41%	0%
	Location four	11%	58%	22%	9%
	Location five	12%	75%	13%	0%

What also became apparent was that properties at location one were the worst affected within this group. Although the percentage in location five is higher regarding very heavy and heavy/medium growth of the Whisky fungus, location one had the largest number of elevations, and thus a greater number of affected properties. Figure 5 reveals that those properties at location one are in the closest proximity of those surveyed to the bonded warehouses amongst the properties in the North-West group.

The properties at location three were not affected by very heavy manifestation of the Whisky fungus; there were still a high number of elevations displaying heavy/medium growth within this location although there are more elevations displaying very light growth than all the other locations. It can be concluded that properties in location three exhibit a range of severity of growth extents; this could be due to the distance spanned by the road and the distance from the bonded warehouses. For example, No.293 (at location three) is significantly closer to the bonded warehouses than is No. 281. No.281 was the furthest property surveyed in distance from the warehouses within the North-West group (Figure 5) and consequently displays a significantly lighter manifestation than that on No.293.

Within the West group of properties situated at Locations four and five, and displayed in Table 1, the extent of the Whisky Black manifestation variation lessened to some extent. The percentage of elevations suffering from very heavy manifestation is similar in each location although location five contains a larger percentage of properties with heavy-medium manifestation and a smaller percentage of properties with light-very light growth than location four. However, in location four there was evidence that some elevations had been cleaned recently; if these properties had not been cleaned it is fair to assess that, judging from neighbouring properties, these elevations would fall within the heavy-medium category. Therefore, if the properties had not been cleaned in location four, they would arguably present similar results to location five in terms of heavy-medium and light-very light extents of fungus growth.

Extent of manifestation of Whisky Black by orientation

When considering the extent of manifestation of Whisky Black by orientation, the results were analysed by the direction in which the elevation faces. Figure 7 illustrates that elevations facing West displayed significantly lower levels of manifestation of Whisky Black than other orientations (not directly facing the bonded warehouses), due to the large number of elevations where the extent of growth was recorded as light-very light or clean. Elevations facing East displayed more manifestation of Whisky Black than other elevations as evidenced by the higher number of elevations recorded to have very heavy and heavy-medium growths of the black fungus. The bonded warehouses are situated to the South-East and East of the properties, which perhaps explains why the East elevations are the worse affected (i.e. in the direct line of the ethanol source).

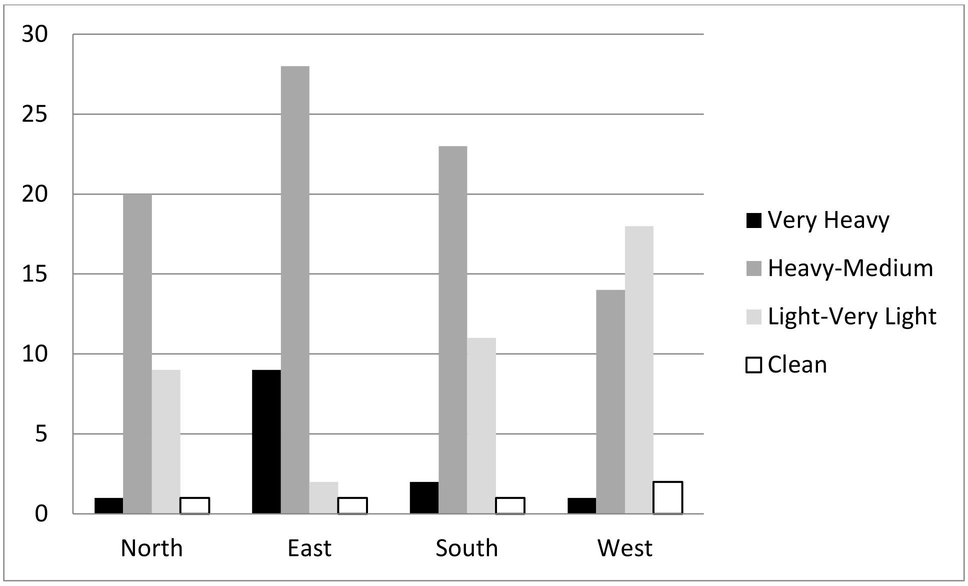

Figure 7: Extent of manifestation by orientation (elevation)

Extent of Manifestation of Whisky Black on different materials

Further to the location and orientation of the properties, construction materials were also considered when collecting research data regarding the extent of manifestation of Whisky Black. Brick, PVC, timber, re-constituted stone and roughcast were deemed the main construction materials used on the external envelopes of the properties in the studied location cross the range of house designs. Table 2 shows how the extent of manifestation of the black fungus varied across these construction materials by both number of elevations and the percentage across each (with multiple materials on multiple elevations).

Table 2: Extent of Manifestation on Materials by number of Elevations

		Very Heavy	%	Heavy / medium	%	Light / very light	%	Clean	%
Manifestation by Orientation (elevations)	**Bricks**	6	11%	30	56%	13	24%	5	9%
	PVC	3	2%	49	40%	68	55%	4	3%
	Timber	4	4%	47	43%	53	49%	4	4%
	Reconstituted Stone	5	4%	47	36%	73	56%	5	4%
	Roughcast	0	0%	47	57%	35	43%	0	0%

Table 2 also demonstrates that bricks experience the greatest extent of manifestation of the fungus, as evidenced by the high percentage of elevations with very heavy and heavy-medium coverage. Table 2 also illustrates the extent of manifestation of each material individually. On some properties the bricks (Rustic faced) had been cleaned, and considering the extent of manifestation on bricks of neighbouring properties, these elevations would most likely have displayed heavy-medium manifestation extents if they have not been cleaned. This would have further demonstrated that bricks are the material most affected by the Whisky Black fungus.

The least affected building materials appear to be PVC and re-constituted stone. Each of these materials has a high percentage of light-very light growth extent of Whisky Black. In addition, the percentage of heavy-medium coverage on these materials is lower than for each of the other construction materials. Again, some of the PVC and re-constituted stone had been cleaned, however, if these materials had not been cleaned on these particular properties they would most likely exhibit light-very light manifestation due to growths on these materials evidenced on neighbouring properties.

The variability of the extent to which the fungus grows on different materials was also shown by Watson *et al.,* (1984), who saw no manifestation of the fungus on copper or zinc-clad surfaces, indicating that low concentrations of copper or zinc ions can act to inhibit fungal growth. Our results suggest that other factors could also influence the extent to which fungal growth can occur.

If the construction materials are grouped to reflect their surface texture, then bricks, timber and roughcast would be described as rough; and PVC and re-constituted stone would be described as smooth. Figure 8 illustrates the materials divided into these groups and shows the extent of manifestation on rough textured materials and smooth textured materials. Rough textured materials (for example bricks) exhibit a heavy-medium manifestation more often than those with a smooth texture. Following the same trend, smooth textured materials suffer from a light-very light growth extent more often than those with a rough texture. Therefore, the extent of manifestation of the black fungus is marginally greater on rough textured materials than on smooth textured materials.

Both groups of textured materials exhibited a small amount of very heavy manifestation. However, this may be more relative to the property on which the materials are located rather than the construction material itself. For example, one property at location one showed a significant manifestation of the black fungus on each elevation, therefore the construction materials on this property exhibited a very heavy, or heavy-medium manifestation. Whereas on a property that is less affected, i.e. No. 131 at location two, the construction materials are affected differently. On No.131 at location two the re-constituted stone and PVC (smooth textured materials) suffered from a light-very light manifestation of the fungus and the roughcast (rough textured material) suffered from a heavy-medium manifestation.

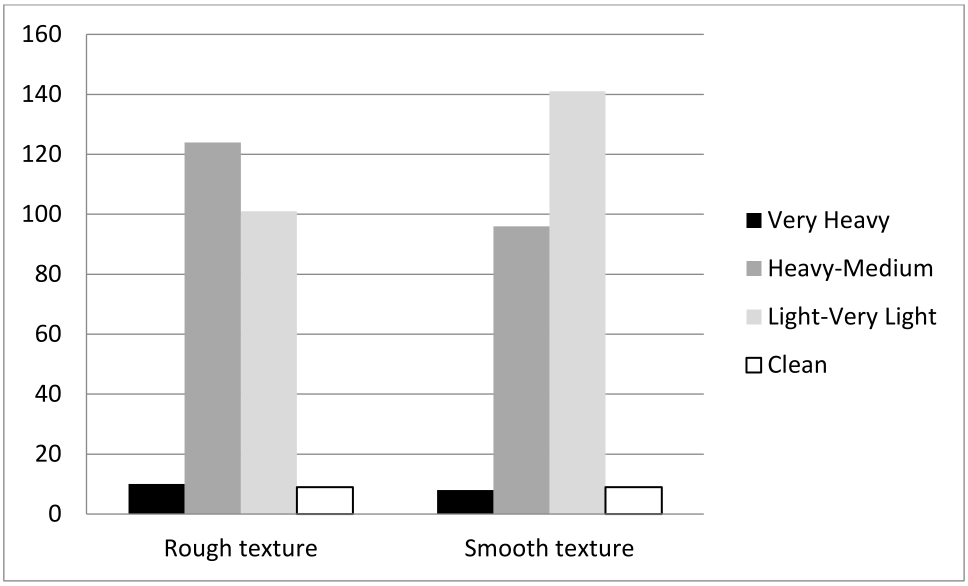

Figure 8: Extent of manifestation by material texture

Additional Observations

During the visual inspections of the fifty properties some additional observations were made with regard to particular elevations. On the majority of elevations there were areas on which the Whisky fungus was not evident or not evident to the same extent as the rest of the elevation. The areas where the Whisky fungus was not as evident was found to be under the eaves of the roof of the property, or under projecting window cills. Areas sheltered by the eaves varied in size, extending to approximately one metre beneath the eaves on some properties. Areas protected by projecting cills were smaller in size and reached approximately 0.3m beneath the projection. Figure 9 shows the areas beneath the eaves (shown by the black arrows on Figure 9 and the white arrows on Figure 10) and the window cills having a lesser extent of Whisky fungus growth than the remainder of the external wall and therefore the 'soiling' not being uniform across the surface. Figure 10 demonstrates the manifestation of the black fungus on a heavier scale with areas beneath the eaves again not uniform in coverage and also the exterior wall of the integrated garage which had been cleaned of the Whisky fungus. Areas sheltered by eaves and projecting cills will also be protected from rainwater, whereas the rest of the building envelope will be exposed to rainwater. Therefore, this confirms that the Whisky fungus prefers damp climates and requires some degree of moisture in order to grow.

Figure 9: Heavy-Medium elevation demonstrating lack of growth beneath the eaves.

Figure 10: Elevation with very heavy growth demonstrating non-uniformity of growth beneath the eaves.

Discussion

The paucity of literature on this subject suggests much is still unknown in our collective understanding of the implications of *B. compniacensis* upon building performance. The key inductive stages of building pathology were used to direct the approach to determining the growth and soiling of *B.*

compniacensis on properties near a bonded warehouse. These stages are manifestation, diagnosis, prognosis and therapy.

It has been shown in this research that certain variables affect the ability of *B. compniacensis* fungus to propagate including:

i. The distance from the bonded warehouses to the manifestation locations,
ii. The wind direction from source,
iii. The environmental conditions - rain fall intensity and moisture affects growth on certain elevations and beneath run off areas,
iv. The moisture retention in the building fabric specifically forming the substrate,
v. The material types that form the substrate, surface texture and roughness.

***Manifestation* -** In relation to the visible signs of the occurrence of *B. compniacensis* soiling, early research in the 1980s (Watson *et al*,1984) indicated that the black fungus was found up to 100m from the boundary fence of the bonded warehouses. However, more recent research by Ing *et al* (2018) indicates that the Whisky Fungus was found on trees at one particular location in Northern Scotland between 163 and 608 meters from the buildings in question.

In our study, in line with Watson *et al* (1984), the affected residential properties were approximately 100m from the source if considering only the distances from the closest bonds to the residential buildings. However, when considering the actual 'centre' of the bonded warehouses the colonisation was occurring at over 500m, although the extent of this was not as prevalent as the close distances. This particular case study also studied locations that were perpendicular to the prevailing wind and Whisky Black. This is significant both for its colonisation here, and for elsewhere in the world, as it appears to thrive even where the wind source could be considered as being against local conditions.

Two factors appear to significantly influence the level of soiling caused by Whisky Black: the presence of ethanol, and substrate materials. Indeed, the results show the extent of the manifestation of the fungus is considerably affected by different types of construction material, and it was found that rough textured materials (for example bricks) are prone to greater levels of heavy-medium growth of *B. compniacensis* than smooth textured materials (such as PVC) at the same distance and environmental conditions.

Another important factor influencing the prevalence of growth of *B. compniacensis* was associated with building designs, and more specifically the design of weathering detailing such as projecting eaves on pitched roofs and cills around the manifestation. With respect to our results, there were areas surveyed where the fungus was not as prevalent as in other areas, or at least not to the same extent as the rest regarding a particular elevation. The areas of elevations where the fungus was not uniform in manifestation were areas directly beneath the window cills and the eaves of the roof, or areas where the moisture content is lower and the area is protected from rainfall. In contrast, the remainder of the elevation is exposed to the elements, thereby indicating that Whisky Black requires both the ethanol and an increased substrate fabric moisture content to sustain successful growth and propagation. This is in agreement with the proposed life cycle of the fungus requiring liquid water on a surface in order to allow growth (Scott and Summerbell,2016).

Diagnosis –

A primary factor in the growth of *B. compniacensis* is the importance of climatic conditions, twinned with an ethanol food source. The relationship with moisture and *B. compniacensis* growth is clearly established (Scott and Summerbell, 2016), and given that climate change data for Scotland predicts increasing rainfall intensity, the potential ramifications for growth of the fungus is increased given that the substrates will be wetter for longer. It can therefore be hypothesised that climate change rainfall patterns may increase the prevalence of Whisky Black in the longer term due to favourable growth conditions. However, further research is needed to determine the true extent of Whisky Black growth in relation to predicted future rainfall, although it would be logical to assume that if the cause of the soiling were from other sources, then the soiling patterns would be noted across the wider urban environment.

***Prognosis* –** Further research into the potential implications of *B. compniacensis* on the building materials composing the external envelope is required. It has not yet been established if building materials will deteriorate from experiencing particularly heavy or long-term prevalence of the fungus, or whether the performance and durability will be compromised (i.e. accelerated deterioration via moisture entrapment) or enhanced (i.e. protective effect of crust formation). To consider the implications for the longevity or performance of the materials further testing is required.

The implications of reduction in building value is of concern to the communities, and whilst all buildings ultimately soil and develop 'patina' this would not be expected to occur rapidly or to high degrees outside heavily polluted urban environments (associated with car pollutants). In terms of understanding its prognosis, the fungus has been seen to have an effect on residential properties, buildings, street furniture and vegetation, yet it is still unknown what affect it has medically and whether it is deleterious to health. Exploration of the potential health issues related to the presence of Whisky Black is arguably required.

***Therapy* -** In relation to approaches to therapy, it was also noted during the research that many residential homeowners clean their properties with high-pressure water washers and chemicals as an approach to therapy, and presumably in an attempt to improve their building's appearance. However, it could be argued that they are unaware of potential additional problems they may be causing to the building structure and fabric through inappropriate cleaning techniques. Additional cleaning is not only costly but may have an effect on health, especially as the fungus particulates may become air borne during the removal process. Preventative measures may be considered, for example the use of biocides prior to painting, but these themselves have been shown to adversely affect substrates, thereby causing accelerated decay in certain materials. Thus, research of safe cleaning methods to remove the fungus from the external surfaces of buildings should be explored

It is logical that if a causal relationship can be formed between the food source (the ethanol) and the growth of *B.Compniacensis,* then stopping the ethanol at source would be beneficial. It is however recognised that atmospheric ethanol dispersal occurs from diffusion through bonded warehouse fabric, and cannot be associated with any single primary source (perhaps capturing the ethanol as it is liberated from barrels could be one option). All options should be explored and feasibility studies carried out to investigate the effectiveness of any equipment in bonded warehouses.

Conclusions and key recommendations

Much previous research has established that ethanol feeds the growth of a black fungus on a range of materials in proximity to where this ethanol is released into the atmosphere from the barrels in bonded warehouses where spirits are matured during their production. Whisky is one such spirit that is matured for often very long periods of time, leading to the release of ethanol from bonded warehouses over a sustained and lengthy period. Whilst many distilleries are set in picturesque rural surroundings, whisky production on an industrial scale also involves its maturation in bonded warehouses in more urban environments with many residential properties nearby. This paper surveyed the colonisation of the fungus *B. compniacensis,* also known as Whisky Black, on the urban environment surrounding an area of potentially rich ethanol dispersion by drawing on a building pathology framework that considered the manifestation of the fungus. This novel approach adds to the literature by comprehensively surveying the growth of the fungus in the urban environment. The paper adds to the body of evidence that creates a causal link between the food source of the fungus (the ethanol) and the growth of the fungus up to nearly 500 metres from the food source. Specifically, the results show the variables that affect the ability of the fungus to propagate include the following: distance from the ethanol source to the manifestation of the fungus; the direction of wind from the ethanol source; environmental conditions such as rainfall intensity and moisture levels; the moisture retention properties of substrate building fabric materials, and; substrate material types, texture and roughness. Indeed, these latter findings on material surface characteristics may influence specifications for materials in new-build properties in affected areas.

Whilst the fungus is considered benign and largely an aesthetic problem for homeowners, this should not detract from the potential unintended consequences of the growth on the value of property. Distillers deny responsibility for this problem despite a growing body of scientific evidence that the fungus exists as a consequence of the ethanol vapours they produce. Yet, it is arguable the above results here show that investigating whether a reduction or elimination in the potential food source material (i.e. the ethanol that the fungus depends upon) should be undertaken to identify whether it can reduce fungus growth. Given the global nature of the spirits industry and its importance to the global economy, and given the scale of the issue and of the impact it could potentially have worldwide, it is prudent for further research to be undertaken to investigate these issues, and recommendations for these are outlined here below.

Key Recommendations

It is recommended that further research be conducted to understand more about the manifestation, diagnosis, prognosis and therapy for the fungus from a Building Pathology perspective (BRE, 1982). One avenue of research could investigate the manifestation of the fungus on a range of substrate materials to identify which materials are most resistant to any manifestation and under what conditions. Further, examinations of wind direction, distance from the bonded warehouses and growth of the fungus overall could extend our understandings of diagnosis. Longitudinal studies of the fungus's impact on materials and human health could enhance our knowledge of prognosis and studying the effects of different biocides on the fungus's presence on different substrates could further expand knowledge of appropriate therapy. This could also help determine whether the removal of the fungus via cleaning techniques results in greater damage to the substrates than the fungus itself, particularly given the historic precedence for accelerated decay in cleaned materials.

Subsequently, how to successfully reduce ethanol emissions from bonded warehouses could be identified, and the use of oxidisation equipment is believed to reduce the amount of ethanol released into the air without affecting the overall end product, i.e. the spirits produced. This could thereby limit the effect of *B. compniacensis* on properties surrounding bonded warehouses and capture the ethanol at source using cleaner production methods, arguably a more effective approach than any remedial treatments.

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